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Bottom Boundary Layer Stress Measurements with BASS Tripods: Data Report STRESS 1988-89

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by

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Technical Report

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Authors' Note: In this report, the height above bottom of the top-most sensor of BayShore IV is specified as 440 cm above bed. Subsequent to the generation of this report, it has been noted that the field log indicated the height above bottom as 499 cm above bed. The 499 cm height has been verified and should be corrected by the reader on Page 2 and in Figure 1.

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Data Report STRESS 1988-89

Thomas F. Gross†

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Overview

The Benthic Acoustic Stress Sensor tripods, BASS, are bottom landing instrument platforms designed to measure the turbulent bottom boundary layers. The turbulent bottom boundary layer is the turbulent flow in the region from the sediment bed to 5 to 10 meters above the bottom. Within this region turbulent stress slows the flow from midwater column speeds to zero at the "no-slip" condition of the sea bed. Boundary shear stress scales sediment erosion rates and provides boundary friction which affects the full water column momentum balance. The stress is due to the mean boundary layer shear and enhanced by wave generated turbulence. Therefore measures of the mean profile and wave action are needed, as well as a modeling method by which the bed shear stress can be derived. The Grant, Madsen and Glenn models of wave-current interaction will be used for this.

The sheared velocity profile is to first order a logarithmic profile described by $U(z)=u_*/\kappa \ln z/z_o$. The shear velocity scale, u_*, describes the turbulence intensity and is used to derive the boundary shear stress $\tau_o=\rho u_*^2$. These quantities are measured by obtaining velocity profiles at half hourly intervals through the bottom 5 meters of the flow.

The wave action is derived by obtaining pressure power spectra every half hour. From this a peak frequency and pressure variance are obtained. By using linear wave theory these are related to the near bed wave velocity and excursion amplitude. The validity of these conversions are checked by comparison to velocity variance which is dominated by wave motions.

The BASS tripods provide turbulent bottom boundary layer descriptions by measuring the velocity at six fixed locations within 5 meters of the bed. The mean velocity data is used to derive logarithmic profile estimates of u_*. In addition the BASS velocity data, which is sampled at 1.6 Hz, can provide estimates of kinetic energy and the Reynolds stress tensor by averaging velocity component cross correlations:

$$<u'_i u'_j>=\frac{1}{30min}\sum_{t=0}^{30min} U_i(t)U_j(t)dt \;-\; \overline{U}_i\overline{U}_j$$

where $U_i(t)$ is the original time series data, $\overline{U}_i$ is the average over 30 minutes

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and u'_i is the turbulent velocity component.

Data Results

The BASS tripods were deployed twice at the STRESS site, Table 1. During the first deployment one six BASS tripod was put down at the 90m C3 station, data tape T2000. The second deployment put that same tripod at the 90m site, data tape T2006, and another four BASS tripod at the inner shelf C2 station in 55m, data tape T2005. Calibration zeros were obtained for both tripods after the second deployment. Zeros were obtained by bagging the instruments to prevent flow through the sensors and placing them on the bottom at the Sausalito dock.

BASS tripods were deployed at the STRESS sites winter 1988-89. Three data tapes were recovered:

T2000:
Turn on: Nov. 28 18:30 GMT = 332.7708 year day (y.d.)
In water: Nov. 28 21:30 GMT 1988 = 332.8958 y.d.
to Jan. 24 9:30 GMT 1989
90 meter site, Bayshore IV BASS, Clean tripod,
Six BASS pods at 22.6, 53.1, 113.2, 198.9, 259.4, 440 cm above bed.
Two Transmissometers at 46 and 144 cm above bed
Eight thermistors at 40, 65, 113, 204, ...
Pressure sensor 4 cm above bed, serial number 13032
Compass: unknown, *not recorded*

T2006:
Turn on: Jan. 26 21:00 GMT 1989 = 25.8750 y.d.1989 = 390.8750 y.d.1988
to Mar. 18 15:30 GMT, 1989
90 meter site, Bayshore IV BASS, Clean tripod,
Six BASS pods at 22.6, 53.1, 113.2, 198.9, 259.4, 440 cm above bed.
Two Transmissometers at 46 and 144 cm above bed
Eight thermistors at 40, 65, 113, 204, ...
Pressure sensor 4 cm above bed, serial number 13032
Compass: 266°, Rotate U to EAST with addition of 90-266-25-16.9=152°

T2005:
Turn on: Jan. 25 19:00 GMT 1989 = 24.7917 y.d.1989 = 389.7917 y.d. 1988
In water: Jan. 25 22:00 GMT 1989 = 24.9167 y.d.1989
to Mar. 17 22:30 GMT 1989
55 meter site, Glass BASS, LDV tripod,
Four BASS pods at 41.5, 76.5, 111.5, 510. cm above bed.
Two Transmissometers at 50 and 148 cm above bed
Three thermistors at 46, 112 , 510 cm above bed
Pressure sensor 4 cm above bed, serial number 9126
Compass: unknown, compass defective

Data recorded on each tape:

Month day hour minute
Half hour averages of 1.6 Hz velocities along each of four axes for each pod.
Quality word for each axes of each pod.
Half hour average cross correlations of 1.6 Hz data of pod axes: a'a', a'b', a'c'...etc.
Ten minute readings of thermistors and transmissometers
Two minute averages of U and V at one level
Fourier transformations of pressure variance, frequencies (1:40)/307.2s :fairly good.
Fourier transformations of velocity component variance,
frequencies (1:40)/307.2s :problematic.

On the second deployment only (T2006, T2005) the following were added:
Compass
Half hourly pressure. Not averaged, so terribly aliased by surface waves.

Calibrations:

BASS velocities

BASS velocity calibrations involve a gain factor and a zero offset. The gain factor is only a function of the path length and speed of sound in water, neither of which are variable, gain = 0.00368 cm/sec /bit. The zero offsets are due to capacitence variations of the cables. This changes slightly with each configuration of the tripod. Therefore zero velocities are measured by deploying the tripod with each pod wrapped in plastic to still the flow. These zero deployments were done off the dock on March 19, 1989 after the experiment. The maximum magnitudes of the zero velocities are 3.77 cm/s. One channel from each pod may be discarded. A large offset zero is an indicator of trouble and is usually the channel which is discarded. Thus the largest offset zero which is used is -0.79 cm/s, (pod 3 is generally suspect on both tripods and will be excluded from the analysis whenever possible). By using these zeros, velocity vectors are obtained which yield logarithmic profile slope with regression coefficients in excess of 0.98 indicating confidence of better than 0.2 cm/s in the mean speed estimates.

Table 1
Zeros (cm/sec) for T2000 and T2006 March 19 20:30 GMT

	pod #					
channel	1	2	3	4	5	6
A	1.4136	-0.1026	-0.0342	-0.6118	0.4370	-0.7638
B	-0.4522	-0.1254	0.0760	-0.4028	0.7410	-0.1520
C	0.7904	-1.2768	-2.6828	0.9500	0.6194	0.6270
D	-0.8816	0.1406	-2.8614	0.4636	-0.7486	0.8816

Zeros for T2005 (cm/sec) March 19 18:30 GMT

	pod #					
channel	1	2	3	4	5	6
A	-	1.2388	3.7772	-0.8930	0.4712	-
B	-	0.7714	-1.5352	0.7980	-1.2160	-
C	-	0.4180	3.2414	-0.7828	-	-

D	-	0.6270	0.2888	0.5130	0.1672	-

Figure 1 shows a few sample profiles. The four symbols for each level represent speed estimates based on three axes, giving four combinations. The quality of the zero calibrations is visually represented by the consistency between estimates of speed.

Transmissometers

The transmissometers directly measure percent transmission, %Tr = 100%*bits/32768. Light attenuation, $\alpha = m^{-1}$, is derived from:

$$Tr = Tr_o e^{-\alpha l}$$

$$\alpha = \frac{1}{l}\log\frac{Tr_o}{Tr}$$

where l is the path length of the light beam and Tr_o is a calibration transmission at zero light attenuation. Tr_o is due to clear water attenuation and an unknown effect from plastic spacers we used to reduce the pathlength from 25 cm to 10 cm. Their attenuation effect has not yet been calibrated. But attenuation is simply offset a constant amount by Tr_o. The preliminary plots use Tr_o=100% Therefore when the transmissometers were working the measures of light attenuation can be seen to go from a minimum of $^-4\ m^{-1}$ which is the offset due to Tr_o to maximum values of 30 m^{-1} which represent light attenuation of at least 26 m^{-1}.

Thermistors

Thermistors will be properly calibrated later this Fall. A rough calibration has been applied:

$$T = 25*bits/65535$$

where bits ranges 0 to 65535 corresponding to 0 to 25 degrees Centigrade.

Pressure FFT calibrations

The Fourier transform of the pressure signal is calibrated with conversions of measured bits to meters of salt water and the various scaling factors contained in the Fourier transform and its gain adjustments. Ultimately the summation over the components of a Fourier transform give the variance of the signal:

$$\sigma_p^2 = \frac{1}{2\pi}\sum_{freq=0}^{freq=1}\tilde{P}^2$$

Where $\tilde{P}^2$ are the squared magnitudes of the pressure spectra. These are written to tape in minimal form and are called "$fftbits^2$". The gain and FFT calibrations reduce to:

$$\sigma_p^2(bits) = \frac{1}{2\pi}\sum_{freq} fftbits^2/20$$

The final conversion is from bits to meters of salt water. The ParoScientific pressure signal is a count given as a 3 byte number, C. The count is converted into a period, T, by inverting the frequency found by the product of count and

sampling rate:

$$T = \frac{1}{(C^* rate)} \qquad microseconds$$

The pressure is given by the equation:

$$P = A(1-T_o/T) - B(1-T_o/T)^2$$

Where A, B and T_o are calibration coefficients with units of PSIA, PSIA and microseconds, respectively. The conversion of PSIA to meters of salt is achieved with: 68.947 millibar = 1. psi; 1 millibar = $(1.0197)^{-1}$ cm water or 1 millibar = $(1.0197 * 1.02813)^{-1}$ cm standard salt water; 1 atmosphere = 1013.3 millibar. So:

$$p = (P * 68.947 - 1013.3)/(1.02813 * 1.0197) \qquad cm$$

A few pressure numbers in counts from data tape t2006 where the depth should be approximately 90 meters are (01647f, 01646c, 01648b)hex = (91263, 91244, 91275)decimal. If rate = .4 these numbers give about 73 meters. The slope of the curve is -47.636 bits/meter salt water. Fig 1 is the calibration curve of meters salt water to counts recorded, or bits. Uncertainity in this calibration is due to my most recent calibration factors for the pressure sensors being from 1982.

Although the full calibration for ParoScientific pressure sensors is non-linear the range of fluctuations about the mean of ~90 meters is very nearly linear. The slope is very near -50 bits/meter salt water. The full calibration conversion is

$$\sigma_p^2(meters^2) = \frac{1}{2\pi} \sum_{freq} (fftbits/50bits/meter)^2/20$$

Derived quantities:

The four components of the velocity vector measured by a BASS pod are rotated into three component Cartesian velocity vectors:

$$\begin{bmatrix} U \\ V \\ W \end{bmatrix} = \mathbf{A} * \begin{bmatrix} A \\ B \\ C \\ D \end{bmatrix}$$

where A is the rotation matrix which takes the four components of a BASS pod into the three Cartesian components. A may be defined five ways. Four matrices are based on combinations of just three axes at a time. The fifth is the average of the other four methods:

$$\mathbf{A}_5 = \frac{-1}{\sqrt{2}} \begin{bmatrix} 1 & 0 & -1 & 0 \\ 0 & -1 & 0 & 1 \\ 0.5 & 0.5 & 0.5 & 0.5 \end{bmatrix}$$

A rotation to put the U,V,W vector into a North,East,Up coordinate system is based on the compass reading. The compass is measured in the pressure case of the BASS. The velocity vector begins in coordinates with U aligned with the A-C axis. The angle of the A-C axis with the compass case for the Clean tripod is 180° + 15°. U will be turned into East so that is another 90°.

Magnetic declination at the STRESS area is -16.9° in 1988-9. The compass angle measured for T2006 was 266°. The total rotation is therefore $\theta = 90° - (266° + 195°) - 16.9° = 332°$. This angle rotation is around the Z axis:

$$\begin{bmatrix} East \\ North \\ Up \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} U \\ V \\ W \end{bmatrix}$$

The ten components of the cross correlations of the four axis of the BASS pod are rotated into the six unique components of the Reynolds stress tensor.

$$\begin{bmatrix} uu & uv & uw \\ uv & vv & vw \\ uw & vw & ww \end{bmatrix} = A * \begin{bmatrix} a'a' & b'a' & c'a' & d'a' \\ a'b' & b'b' & c'b' & d'b' \\ a'c' & b'c' & c'c' & d'c' \\ a'd' & b'd' & c'd' & d'd' \end{bmatrix} * A^T$$

Futher rotations are applied to put $u_i u_j$ into streamline coordinates.

A least squares fit of the logarithmic velocity profile equation, $U(z) = u_*/\kappa \ln(z/z_o)$, yields the shear stress velocity scale, u_*, the roughness length scale, z_o, and the regression coefficient, R^2. Only the current meters below 2 meters were used as the velocity profile deviates from logarithmic above that level.

Linear wave theory can be applied to solve for the near bed wave orbital velocity, u_b, near bed wave induced particle excursion distance, a_b, and the surface wave amplitude, h, given the near bottom pressure variance, σ_p (meters = P/ ρ g), and the wave frequency, f, obtained from the spectra.

$$k = 2\pi \frac{f}{\sqrt{g\delta}}$$

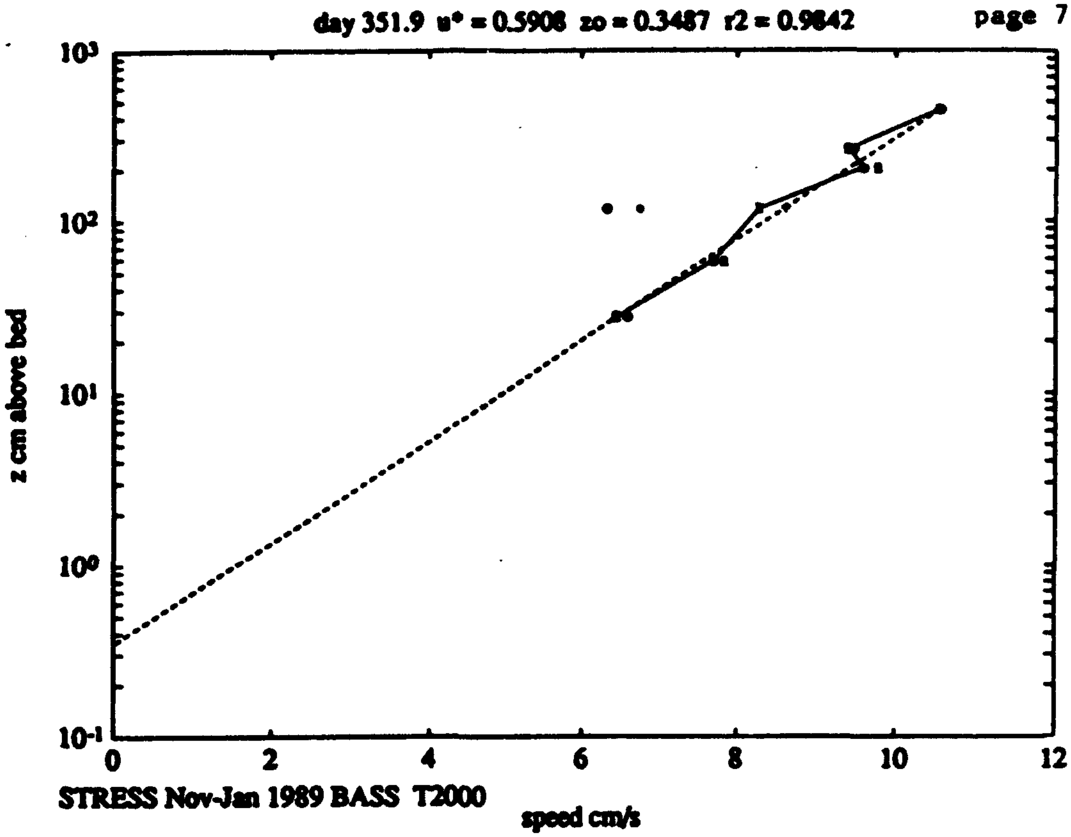
$$\omega = 2\pi f$$

$$u_b = 2\sigma_p \ \omega \frac{\cosh(k\delta)}{\sinh(k\delta)}$$

$$a_b = 2\sigma_p \ \frac{\cosh(k\delta)}{\sinh(k\delta)}$$

$$h = 2\sigma_p \ \cosh(k\delta)$$

The wave velocity u_b will be the major contribution to the kinetic energy or the trace of the Reynolds stress tensor. If this is true then $q^2 = u'u' + v'v' + w'w' = \frac{1}{4} u_b^2$.



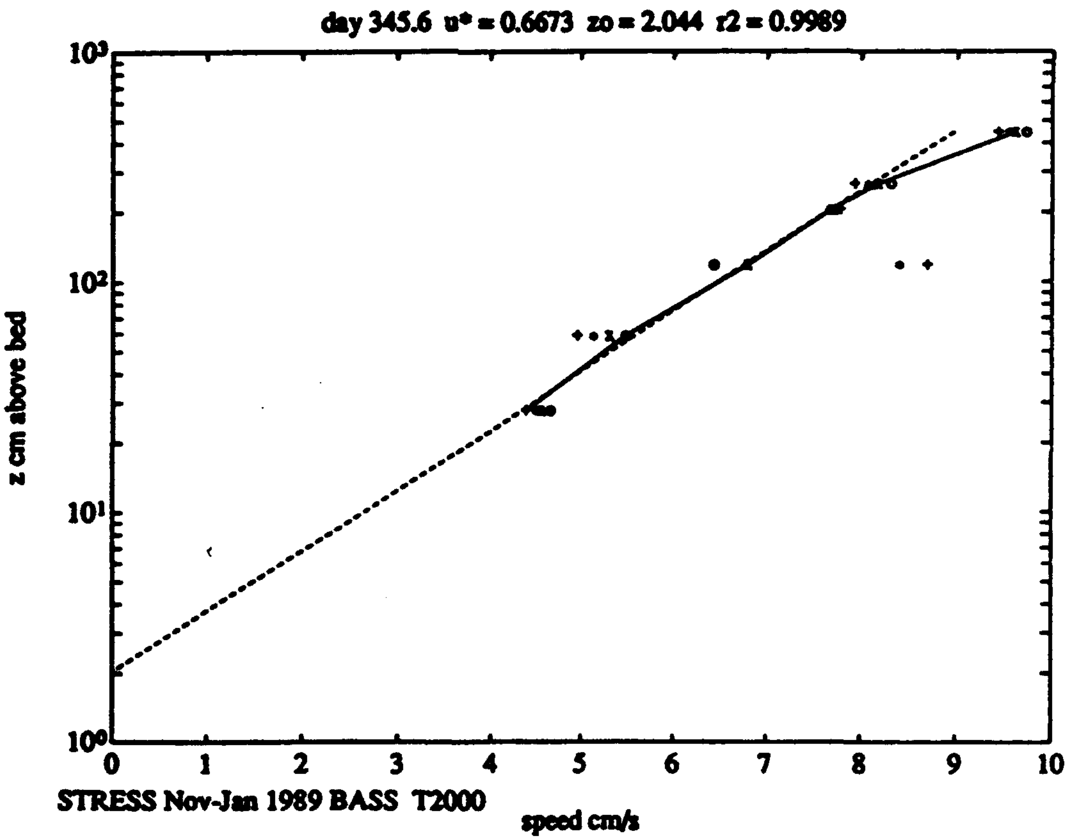


Fig. 1. Sample speed profiles showing the four possible calculations of speed based on choosing three of the four BASS axes, (symbols o,*,x,+). When one axis is bad, three methods of calculation use that axis and result in erroneous estimates.

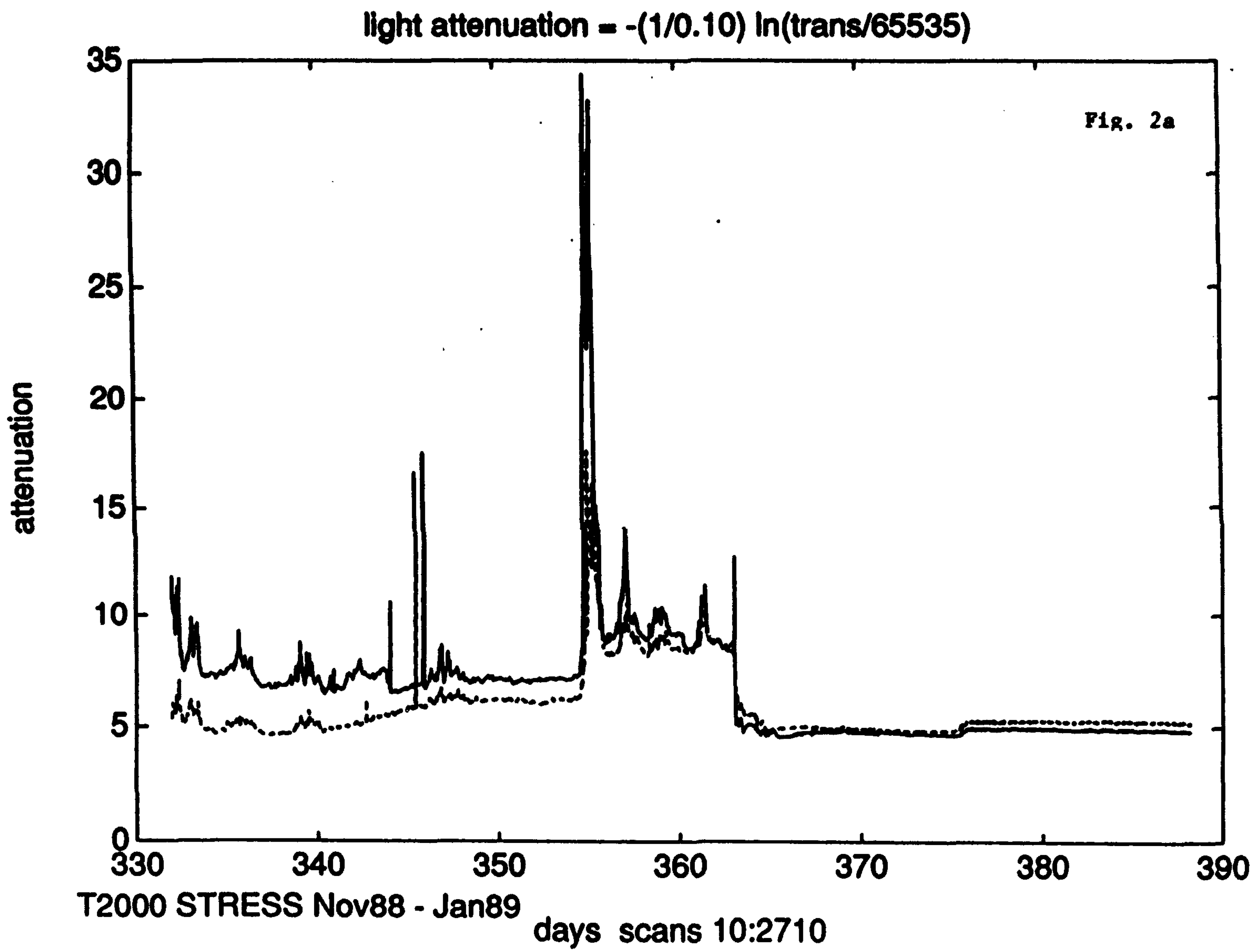
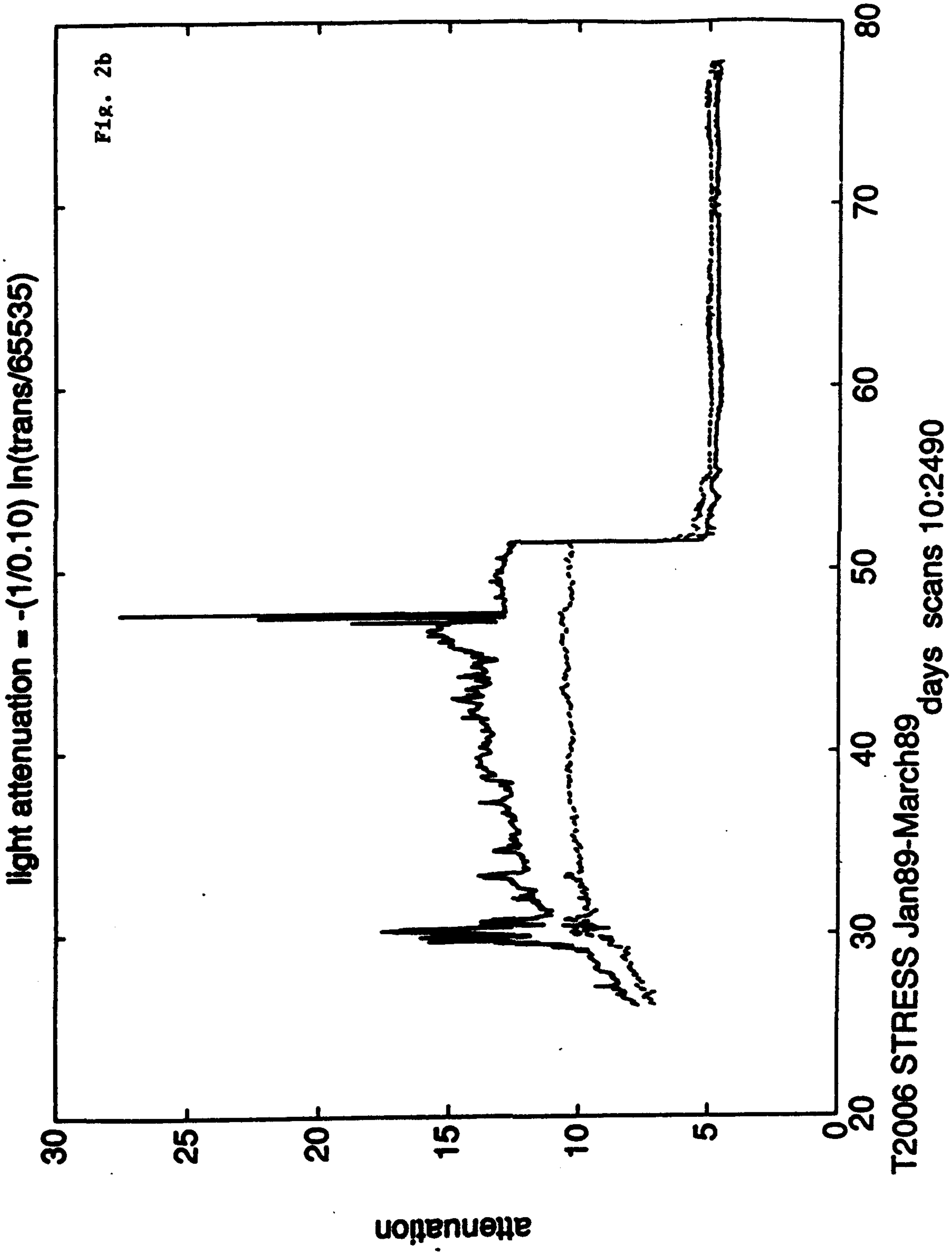


Fig. 2(*a*, *b*). Light attenuation from the two transmissometers. The event on day 355 appears real, but trouble on day 362 and again on day 51 deplete confidence in the remainder of the records.


light attenuation = -(1/0.10) ln(trans/65535)
Fig. 2b
attenuation
0
5
10
15
20
25
30
20
30
40
50
60
70
80
T2006 STRESS Jan89-March89
days scans 10:2490

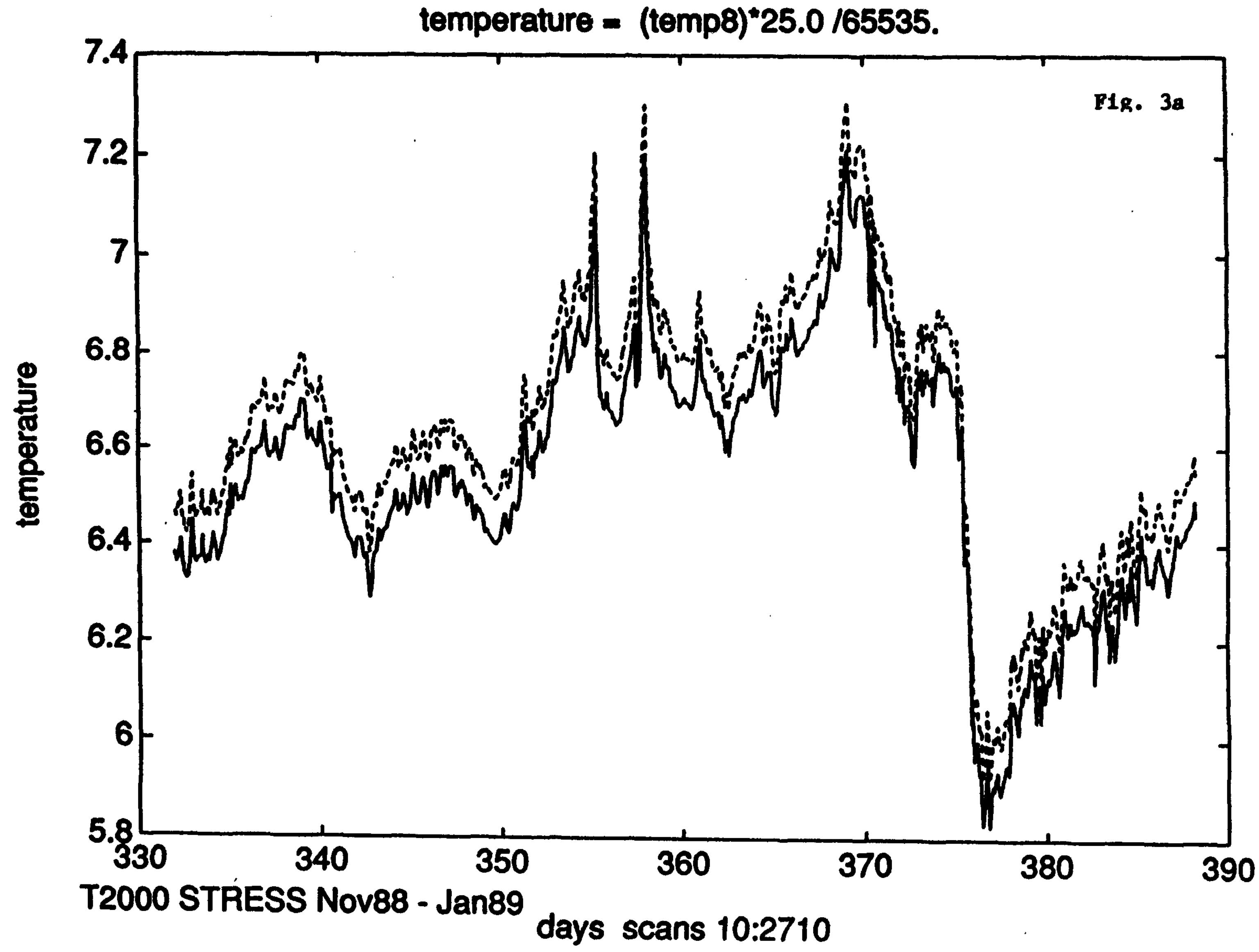


Fig. 3(*a*, *b*). Temperature records for the deployment. The uppermost and lowest thermistors are shown.

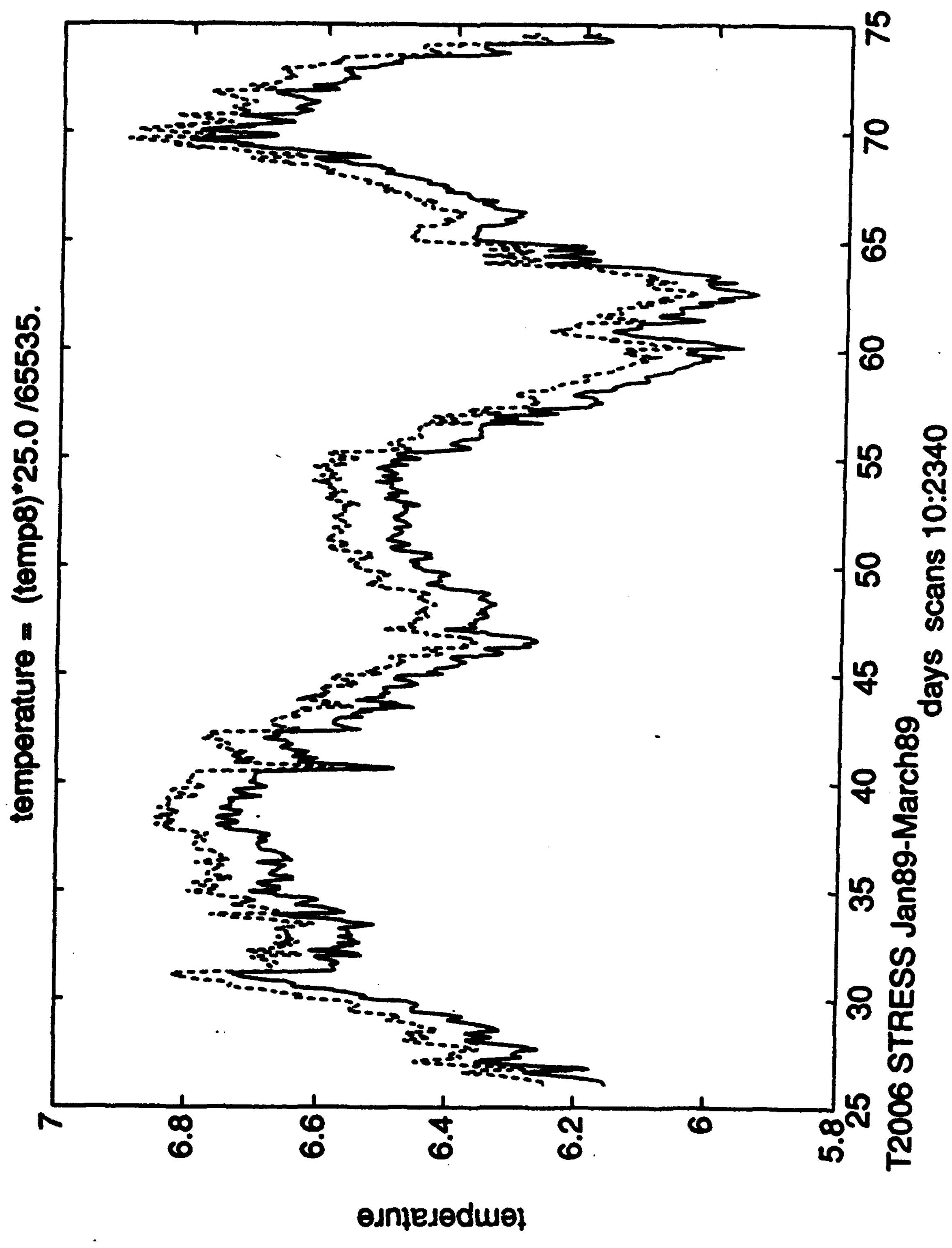

temperature = (temp8)*25.0 /65535.
temperature
7
6.8
6.6
6.4
6.2
6
5.8
25
30
35
40
45
50
55
60
65
70
75
T2006 STRESS Jan89-March89
days scans 10:2340

Fig.3b

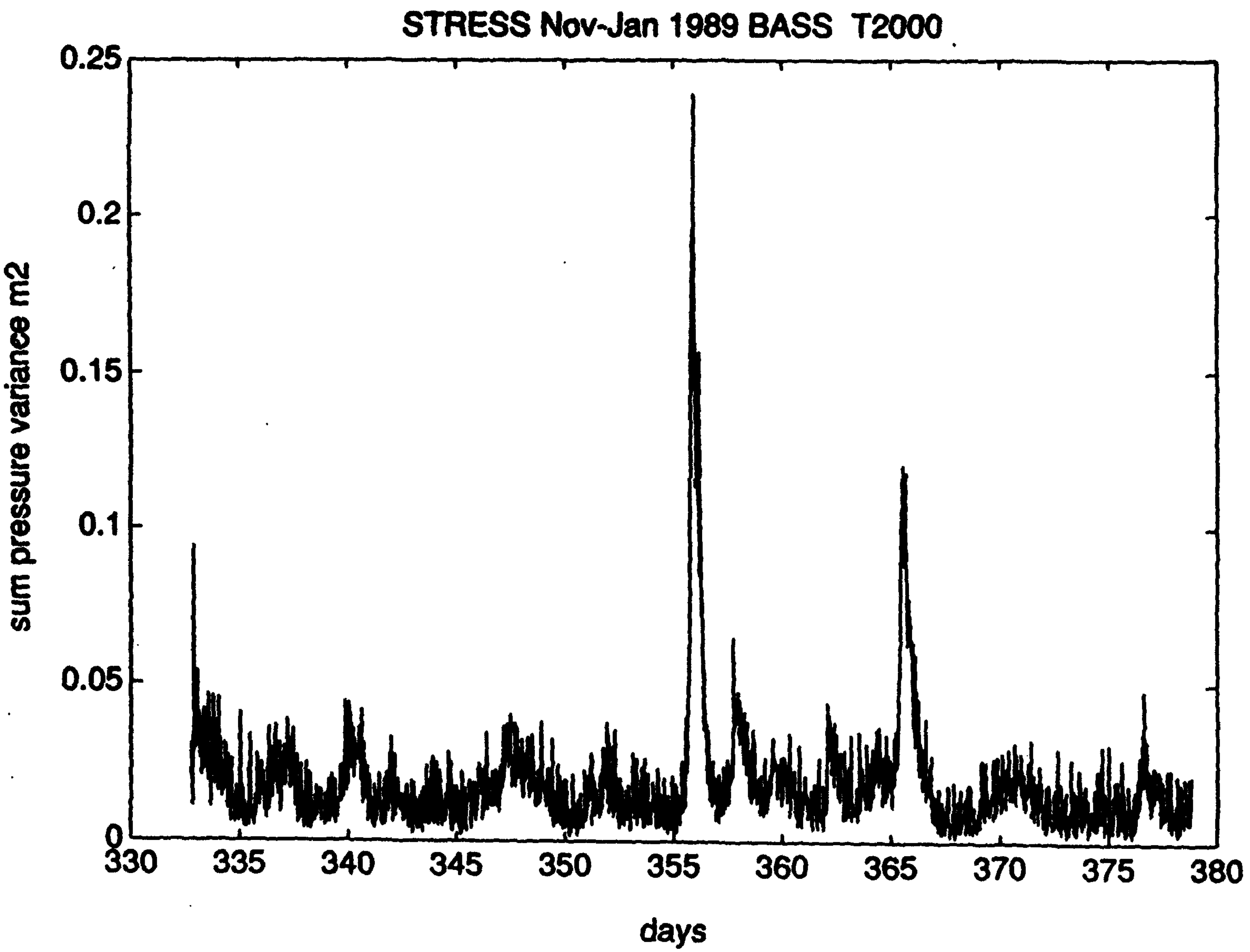


Fig. 4. Total pressure variance derived by summing the FFT estimates across frequencies 0.003255 to 0.1302 Hz.

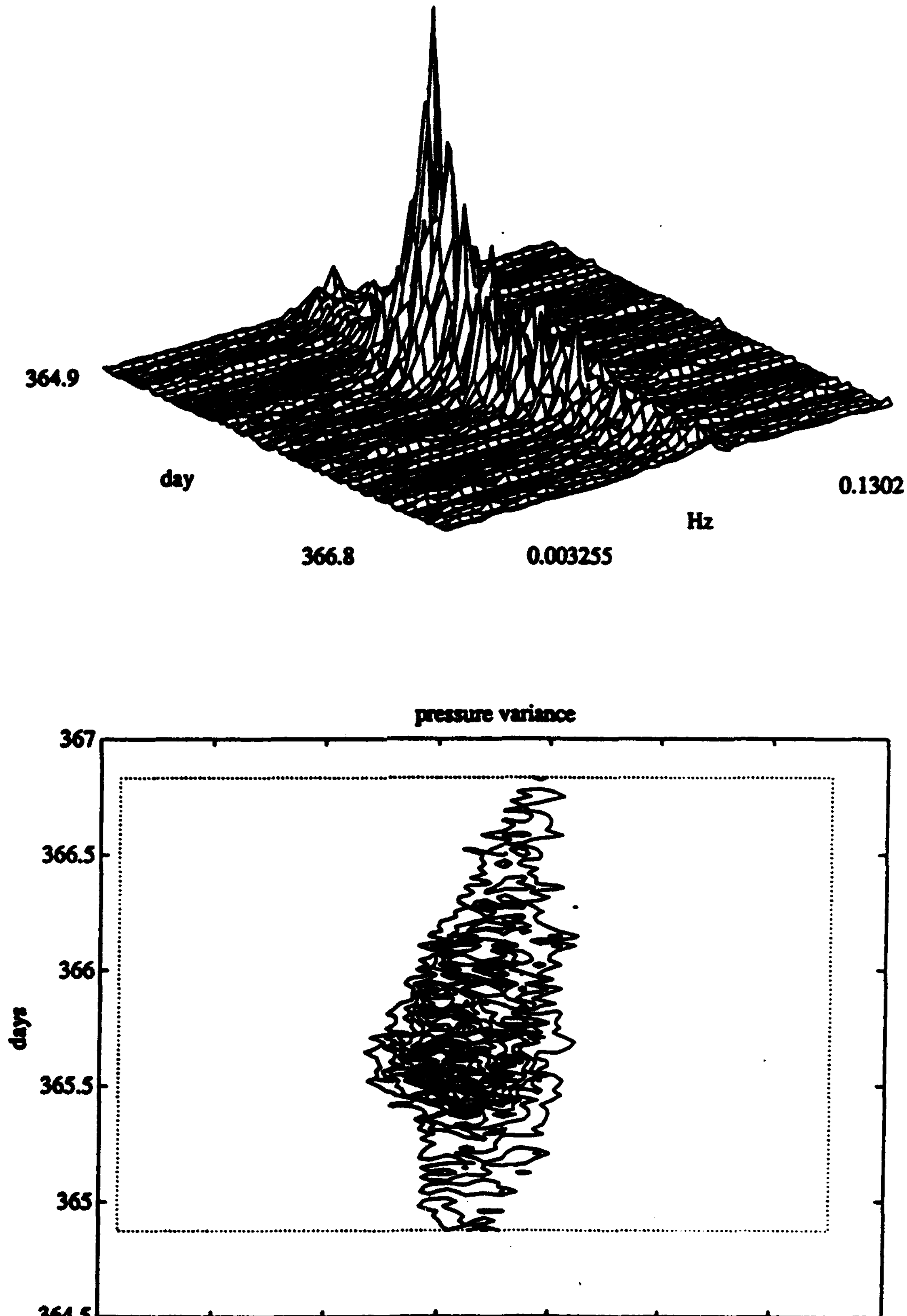


Fig. 5. Pressure spectra presented for the duration of the New Year's storm.

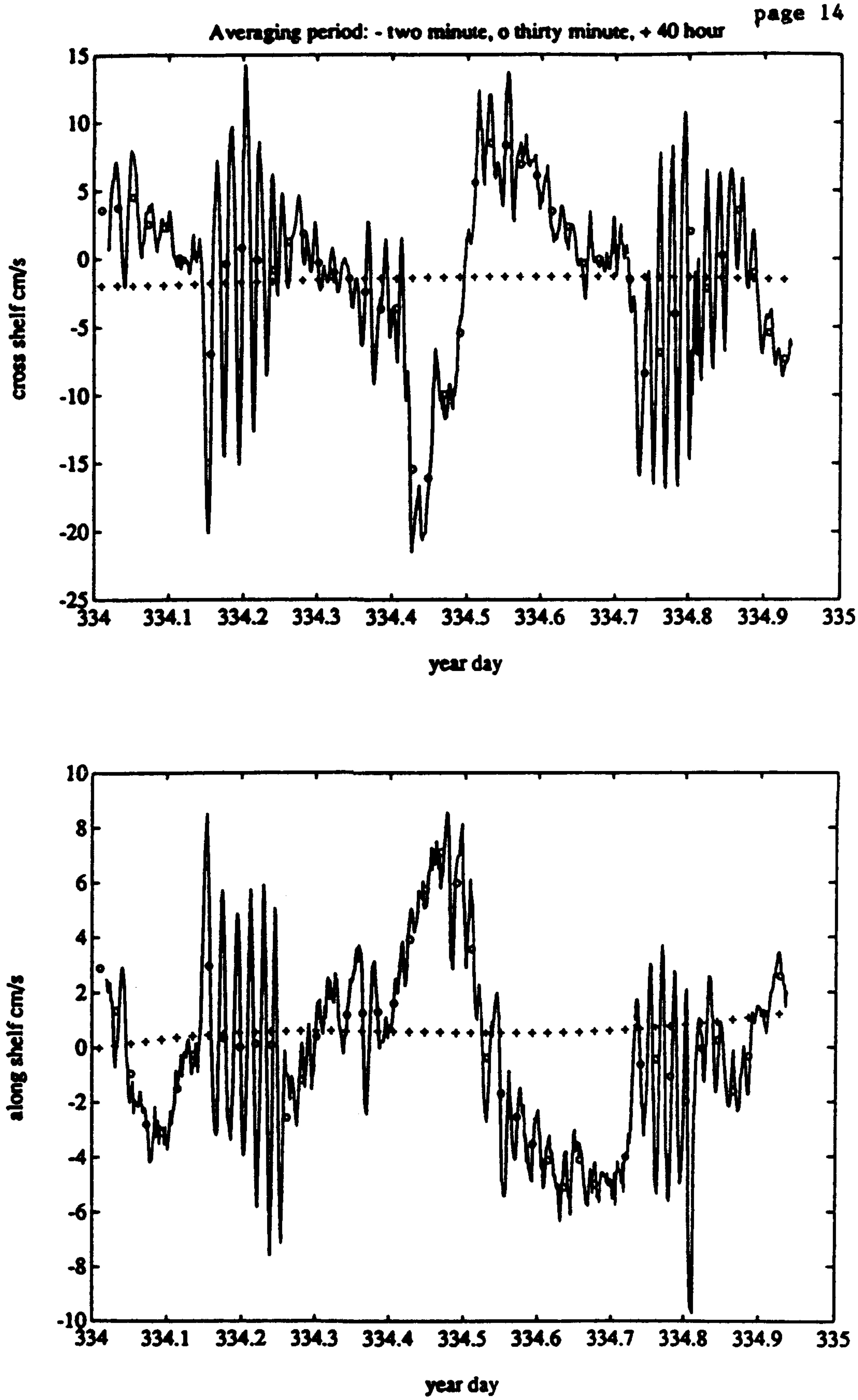


Fig. 6. Two minute average velocity at 1.1 mab (solid lines), thirty minute averages (*o*), forty hour low pass filtered (+). This sample shows dramatic internal waves when the mean velocity was small.

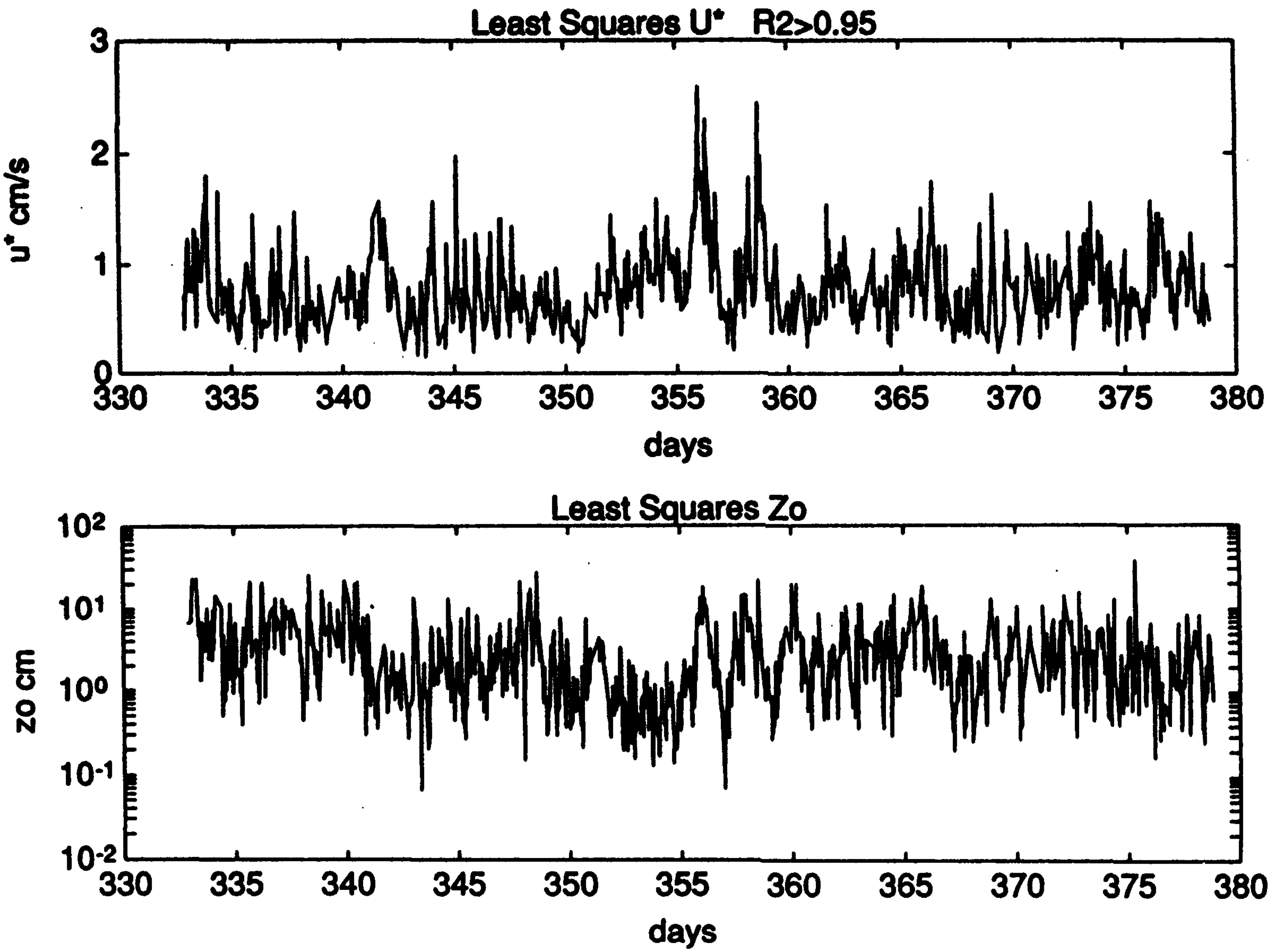


Fig. 7. Least squares estimates of the slope of the logarithmic velocity profile yield u_* and z_o. This plot shows only estimates for which R^2 is greater that 0.95.

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16. Abstract (Limit: 200 words)

Two Benthic Acoustic Stress Sensor (BASS) equipped tripods were deployed in the Sediment Transport Events on Shelves and Slopes (STRESS) experiment in November, 1988, and recovered in March, 1989, on the California Shelf. They measured velocity profiles in the bottom boundary layer over the lowest 5 meters. Transmissometers, thermistors, and a pressure sensor on each tripod provided suspended sediment concentration, stratification, and wave spectral information, as well.

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sediment transport
boundary layer stress

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